ELECTRIC FLUID PUMP

Field of the Invention

The invention relates to a pump driven by a brushless direct current (DC) motor. More particularly, the invention relates to any fluid pump system using DC brushless motor technology to drive coolant (for water pumps) or oil (for engine and transmission pumps).

Background of the Invention

The most common pump accessory arrangement found in automobiles utilizes the engine rotation to drive a shaft via a belt connection between a driving pulley (connected to the crankshaft) and a driven pulley. These belts and pulleys are cumbersome, bulky, noisy, and transfer power (torque) inefficiently. Another disadvantage is that these pumps have their output dictated by the rotational speed of the engine. Certain accessories that are coupled to the engine, such as the coolant and oil pumps, must be over-sized, because the pump output must deliver a minimum flow amount of fluid at low engine speeds. At higher engine speeds, such as those experienced under normal highway driving conditions, the flow amount becomes excessive because it is directly proportional to engine speed, which is up to an order of magnitude greater. This leads to poor efficiencies and increased power losses due to the requirement for a bypass.

Therefore, it is desirable to have the pump output to be independent of the engine speed, and to be adjustable to match the operating conditions. This object can be fulfilled by utilizing an electrically driven pump for supplying coolant or oil to an internal combustion engine.

An early example is disclosed in British patent GB 1482411, which discloses a coolant pump driven by a brush-type electric motor. Later examples of brush type electric motors include US Patent No. 5,540,567.

In general, for any DC motor to operate, the electric current to the motor coils must be continually switched relative to the field magnets. For commutation to occur, power is applied to the motor's windings to produce torque. In a brush-type motor, carbon brushes contact a slotted commutator cylinder, which has each motor coil connected to a corresponding bar of the

commutator. Brushless motors differ in that the windings are located on the stator and do not move, while the magnets are on the rotor. The position of the rotor is sensed and continually fed back to an electronic commutation control to provide for appropriate switching. Advantages of brushless motors include improved efficiencies, reduced noise, weight and size, and improved durability.

Therefore, the preferred method of driving a fluid pump employs DC brushless electric motors. Known prior art examples include US Patent Numbers 5,158,440, 5,269,663 and 6,213,734, all of which utilize a basic design wherein the magnets are mounted radially around the impeller, with the stator (coils and core) also located around the impeller.

A more compact brushless motor design, sometimes referred to as a "flat style", utilizes an axial arrangement wherein the magnet with multiple poles is mounted axially to the impeller, with the stator being mounted axially to the impeller (facing the magnet face with the poles). A recent example of this design is US Patent No. 6,034,465, which utilizes a flat style magnet with multiple poles on its face, a "back-iron" component to enhance the magnetic field, and an enclosed electronic control for the motor.

This brushless design type, and other known variations in the prior art, employ an aluminum plate to prevent the fluid in the pump from reaching the stator, as well as separating the stator from the rotor. Another function of the aluminum plate is to transmit heat generated in the stator to the liquid coolant flowing in the pump chamber. However, while aluminum has excellent heat transfer characteristics, it also decreases motor efficiency. Eddy currents generated in the aluminum by the spinning magnets in the rotor create reverse magnetic fields which retard the rotation of the rotor. This results in a loss of efficiency when converting electrical energy to mechanical power.

Current prior art designs also utilize a stator that comprises a core with a plurality of coils. These coils are located around a post on the core. These posts are limited in size resulting in a "cogging" effect in which the rotor wants to rest in specific positions. This limited size sets restrictions regarding the strength of the permanent magnets and thus limits the maximum output power of the motor for any given motor size.

In light of the deficiencies indicated above, there continues to be a need for pumps driven by brushless electric motors, in particular, for pumping liquids such as coolant or oil in vehicular applications.

Summary of the Invention

The present invention relates to a pump or other accessory whose output is adjustable and is driven independently of the engine. An electric motor replaces the traditional belt and pulley combination.

In a broad aspect, the invention relates to the integration of a brushless DC motor wherein the mechanism to be driven is integral with the motor and not driven through some sort of mechanical coupling. The brushless motor is the actual driving mechanism.

One of the general objects of the invention is to apply brushless DC motors for pump systems for use in automobiles, although the invention has utility in more general use. More particularly, the invention relates to any fluid pump system using DC brushless motor technology to drive coolant (for water pumps) or oil (for engine and transmission pumps).

In a particular embodiment, the fluid pump comprises a housing that includes a plurality of components fastened together, an impeller, a rotor, and a stator with associated windings. The impeller is rotatably mounted within the pump housing for rotation about a rotary axis, in order to force fluid to flow through an outlet of the housing. The rotor is permanently coupled to and rotatable with the impeller, and includes a permanent magnet and "backing iron". The stator is spaced apart from and generally faces the permanent magnetic poles on the rotor. A plurality of magnetic windings is positioned on the stator and serves to effect rotation of the rotor and impeller upon energization.

In an alternate embodiment, the motor housing is a matrix of a polymer and filling compound that gives the polymer good thermal characteristics to allow heat generated in the stator to be transferred through the housing to the coolant or fluid being pumped.

One embodiment implements a stator design in which the core has expanded top surfaces with tapered or bevelled ends. The tapered ends provide a method to increase the

"effective" gap between the stator poles. This allows the stator phases to be closer together resulting in a dramatically reduced physical gap and greatly reducing the "cogging" effect. This feature allows stronger magnets to be used resulting in greater output power for a given size.

In yet another alternate embodiment, the positional feedback mechanism is removed and the motor is operated in "open loop" control mode. This mode is called "open loop" because feedback is not used to control the rotation of the rotor. In this mode, the control circuit turns the stator coils "on" and "off" in a manner that creates a rotating electro-magnetic field. This rotating field interacts with the field of the permanent magnet on the rotor, forcing the permanent magnet to rotate and follow the electro-magnetic field. Regardless of the position of the rotor, the electro-magnetic field will continue to rotate at the predetermined rate.

In an alternate embodiment, the rotor and impeller form a unitary body, in order to reduce the number of parts..

All embodiments eliminate the need for the conventional aluminum plate, resulting in the minimization of drag created by eddy currents generated by the rotating magnets. This results in greater efficiency in converting electrical energy into mechanical power. Furthermore, the removal of the aluminum plate allows the motor housing to be molded as a single unit.

In a further alternate embodiment, the housing is molded in such a way as to create channels for fluid to pass from the high pressure side of the pump to the low pressure side. These channels would allow the fluid to traverse the back of the housing to allow heat generated by the control electronics to be transferred through the back of the housing to the fluid and thus cool the control electronics.

Further aspects of the invention are hereinafter described in the following description and drawings.

Brief Description of the Drawings

In drawings which illustrate the embodiments of the invention,

Figure 1 is a cut-away view of the pump in accordance with the preferred embodiment of the present invention;

Figure 2 is an exploded perspective view of the pump shown in Figure 1;

Figure 3 is a top perspective view of the upper housing of the pump;

Figure 4 is a bottom perspective view of the upper housing of the pump;

Figure 5 is a bottom perspective view of the lower housing of the pump;

Figure 6 is a top perspective view of the lower housing of the pump;

Figure 7 is a top perspective view of the impeller and magnet assembly;

Figure 8 is a bottom perspective view of the impeller and magnet assembly;

Figure 9 is a top view of the core with the top plates removed;

Figure 10 is a top view of the top plates of the core;

Figure 11 is a cross-section view taken along line 11-11 of Figure 10;

Figure 12 is an electrical schematic of the motor and control circuit;

Figure 13 is a top view of a pump assembly according to an alternative embodiment;

Figure 14 is a bottom view of the pump assembly of Figure 13;

Figure 15 is a cross-sectional view taken along line 15-15 of Figure 13;

Figure 16 is a sectional view of the impeller and magnet assembly of Figure 15; and

Figure 17 is a top view of the circuit board of the pump of Figure 15.

Detailed Description of the Invention

Referring to Figures 1-8, a pump assembly 100 is shown including an upper housing 12 with a fluid inlet 10 and outlet 11 and a lower housing 15. The upper 12 and lower 15 housing are preferably molded of polymeric material to provide good thermal characteristics and allow heat to dissipate into fluid within the housing. An impeller 20, preferably formed from injection-molded plastic, is seated within the interior volume of the upper housing 12. The impeller 20 is integrally formed with a permanent magnet and "back iron" assembly 8, which also serves as the rotor of a DC motor, to be described shortly. In one embodiment, the plastic impeller 20 encapsulates the magnet and "back iron" assembly 8 due to an overmolding or insert molding operation. Both the impeller 20 and rotor 8 include a central opening to accommodate both a bushing 13 and low friction shaft or spindle 14. The impeller 20 rotates

around the shaft 14 that is fixed to the lower housing 15. The impeller/magnet assembly 20, 8 is separated from the core by an intervening upper wall 45 of non-metallic material which is formed as part of the lower housing 15 and which may or may not have high thermal conductivity characteristics.

Optionally, the impeller bore for the shaft 14 is coated with a mono-crystalline material with extremely low friction characteristics. In this case, a bushing in the impeller is not required and is removed.

The upper housing 12 has non-threaded inserts 51-55 that align with corresponding threaded inserts 61-65 in the lower housing 15 and which accept bolts 71-75 during assembly and attachment of the upper and lower housings 12, 15. A simple gasket 26 serves to seal the upper housing 12 from the lower motor housing 15, which includes a DC motor of the brushless type, with a stator or core 7 surrounded by windings 820, as discussed below.

As illustrated in Figures 1, 2, and 9-11, the pump 100 has a core 7 comprising a toroid plate 80, three pillars 810 and three top plates 310. Around each pillar 810, a coil of copper or other suitable wire 820 is wound for the purpose of generating a magnetic field, whose polarity is dependant upon the direct of the flow of current within the coil. Assembled into, and thus part of the pump 100, is an electronic control assembly 300 including a printed circuit board 70 which switches the coils 820 on and off independently. The core 7, coils 820 and electronics 300 are held in place by an end plate 28 that mates to the back of the lower housing 15. Alternatively, the core plates 310 may be embedded into the lower housing 15. This feature allows the gap between the magnet 8 and the core plates 310 to be precisely maintained from part to part.

Between the printed circuit board 70 and the end plate 28 is a sealing o- ring 27 that provides the necessary tension to ensure the coils 820, core 7 and electronics 300 do not move after assembly. The end plate 28 can be made of any suitable material such as aluminum, steel, copper and polymers, either thermally conductive or not. The core 7 is made of a soft magnetic material such as HyMu 80 or other suitable material. The top plates 310 of the core 7 are designed and arranged to provide a maximum surface area ratio between the face of the magnet

8 and the face of the core 7. This surface area ratio is a key feature in increasing efficiency. As shown in Figure 10 the arrangement of the plates 310 is such that there is a small gap 320 between them, which is necessary to reduce or eliminate motor "cogging". As the gap 320 becomes smaller, the degree of cogging decreases.

In one embodiment as shown in Figure 11, the core plates 310 have bevelled ends 330 on the face of the plate away from the magnet 8 and the edge of the plate adjacent to the plate beside it defining tapered gaps 320 between adjacent top plates 310. This bevelled end 330 increases the "effective gap" for better efficiency in the magnetic circuit while allowing the physical gap 320 to be as small as possible for better efficiency due to reduced cogging.

The DC motor includes components (not shown) such as Hall Effect sensors. The sensors determine the angular position of the magnetic field of the rotor magnet 8. Signals from the sensors are passed through to the circuit board 70, which is part of the electronic assembly 300 located in the distal end of the pump housing. Other methods in which the sensors are not required to control the rotation of the motor, can also be used with this motor type with the sensorless "back electro-motive force" (back EMF) type being the preferred embodiment. The control circuit, illustrated schematically in Figure 12, also includes a driving transistor (not shown) for controlling a driving current to be supplied to the stator windings 820, so that the rotor magnet 8 may be rotated under the control of the circuit.

In a slight variation of the above arrangement, the impeller and rotor are present as a single member. In this case, a suitable construction material would be plasto-ferrite. In this structure, a thermoplastic such as polypropylene serves as the matrix, with strontium ferrite or other suitable magnetic material embedded within. The advantages provided by a single impeller-rotor assembly include easier manufacturing and assembly, and fewer parts.

In operation, the power source is connected to the terminals 1, 2 of the electronic assembly 300 (Figure 12). Upon application of an appropriate voltage, the electronic circuit of the electronic assembly 300 energizes the windings 820 in a predetermined pattern. This switching pattern causes the windings to generate a rotating magnetic field within the stator core 7. This rotating magnetic field interacts with the magnetic field generated by the permanent

rotor magnet 8, causing the rotor 8 to rotate.

Since the rotor 8 is either embedded within the impeller 20, or is the same part, the impeller 20 rotates in direct response to the rotation of the rotor 8 with no coupling or power transfer assembly required. The number of components and physical size of the pump are thus reduced. The impeller 20 includes curved vanes 400, as shown in Figures 2, 7 and 8, that impart centrifugal energy to the fluid passing through inlet 10, urging the fluid to flow under pressure through outlet 11. When the power source is removed the magnetic field in the core 7 collapses and the impeller 20 stops rotating.

In an alternative embodiment shown in Figures 13-17, the pump 200 includes a first flow tube 30 on the low pressure side of the pump 200 extending between the upper housing 12 in fluid communication with the inlet 10 and hollow channelled end cap 40 which closes the end of the lower housing 15. A second flow tube 50 on the high pressure side of the pump 200 extends between the upper housing 12 in fluid communication with the outlet 11 and the hollow end cap 40. This allows a small amount of coolant to flow through the end plate 40 and provide a constant temperature heat sink that can be used to withdraw heat from heat generating components within the pump. The pressure differential between the inlet 10 and outlet 11 of the pump 200 causes coolant to flow through the coolant tubes (30 and 50). The flow direction is as indicated by the arrows 500 and 510 in Figure 15. The material used for the end plate 40 can be any suitable thermally conductive material, such as aluminum, copper, etc.

Although the invention has been described in detail with reference to a specific preferred embodiment, variations and modifications exist within the scope and spirit of the invention as described and defined in the following claims.